AC 2009-888: INTEGRATING PROJECT MANAGEMENT, PRODUCT DEVELOPMENT, AND SENIOR CAPSTONE INTO A COURSE SEQUENCE THAT CREATES NEW PRODUCTS AND PATENTS FOR STUDENTS

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Abstract

The competitive pressures of the global market have brought into sharp focus the need for creativity, problem solving and teaming skills in our engineering graduates. Industry surveys and the ABET requirements clearly confirm that need. For many students this is a culture change requiring them to think out of the box and into the real world of engineering where needs and requirements must be concretely defined and the selection of design solutions is not black and white. This paper discusses a new course sequence that brings together the basic tools of project management with the creative process of developing new products. The two semester course sequence applies project management techniques such as work breakdown structures, Gantt charting, scheduling and quantitative trade-off studies to the process of developing a new product. Specifically, the new product is the subject of the students' senior capstone project which is pursued in teams and addresses specific products to improve healthcare and aging-in-place and products that improve the lives of persons with disabilities. These needs were identified by healthcare professionals in focus group discussions. The teams are mentored throughout the development process by the professionals that initiated the need. The role of these professionals is that of an active and vital voice of the customer fully integrated in the development process. Over the past three years sixty students have followed the senior capstone course sequence and six patentable products have been created.

Background

In 2004, the *Council on Competitiveness* issued its final report on the National Innovation Initiative called "Innovate America[1]." Clearly America's focus must change from optimizing and incremental improvements to mobilizing our whole society for innovation. The future of America is in returning to the core capabilities of innovation and exploration, in essence, returning to what we do best. The Council made recommendations in three broad categories: creative talent in a culture of collaboration and "symbiotic relationship between research and commercialization," investment seeking "to give innovators the resources and incentives to succeed," and infrastructure with the creation of "new industry-academia alliances . . . . and flexible intellectual properties regimes" [1]. Western Carolina University (WCU), a regional comprehensive institution founded in 1889 with a distinguished history of teaching and learning for western North Carolina has begun the process of alignment with a new focus on innovation. WCU has launched an initiative to engage the resources of the university, its faculty, students, and facilities in the economic growth of the region. At a regional summit held at Cullowhee, NC in February 2003, the university was asked to explore engagement in non-traditional and creative ways [2]. Since that time, numerous initiatives have been launched to stimulate this engagement in new product development, in broadband communications, in adaptive devices, and in rapid prototyping. The conditions are primed for innovative initiatives to convert this enthusiasm into reality. The curricular sequence which combines project management, new product development and the student senior capstone project is in full alignment with these recommendations and

Figure 1. Western Carolina University is in the southern most extension of rural Appalachia.

forms part of the transformation of rural western North Carolina into this new economic model. Our purpose was to produce engineering graduates who are open to the injection of new ideas, comfortable in an environment that will nurture new product ideas from diverse disciplines and can mature promising ideas into actual business propositions.

Regional Context

The western North Carolina region is made up of the 23 western-most counties of North Carolina (shown in Figure 1). This region is larger than eight U.S. states and is approximately the size of Maryland. The demographics of the region are largely rural with a rural population of almost 60% as compared to the entire state ratio of 39.8%. North Carolina ranks the highest in rural population among the twenty most populous U.S. states. Western North Carolina has a rich history in manufacturing — primarily furniture, textiles, and paper. Over the past 20 years, however, and, specifically in the 2001-02 economic slowdown, these industries have been decimated, losing jobs to off-shore-competition and changing market conditions. Sixty nine percent (69%) of textile industry layoffs in 2001-02 occurred in rural North Carolina communities [2]. In the present recession, employment erosion continues to occur. The manufacturing base of the region is predominantly small businesses and manufacturing units. With that situation comes the long list of challenges that face rural regions including lagging infrastructure, isolation by distance, and weak economic competitiveness.

The North Carolina Board of Science and Technology [3], in its "Tracking Innovation: The North Carolina Innovation Index" reports for 2000 and 2003, recognized that, despite the State's ranking in the top five in the nation on technology development, patents, and startups, the

benefits of this growth do not translate into uniform benefits for all its citizens. This growth remains largely concentrated in the Research Triangle and the Charlotte areas. Two of its key findings in the 2003 report were that North Carolina needs to strengthen the training of its citizens, particularly its new graduates, for the knowledge-based economy and needs to enhance intellectual property and technology transfer in the marketplace. The need for innovative and adaptable engineers is more pronounced in today's struggling economy.

Figure 2. The founding partners of the Collaborative represent the principal stakeholders in the healthcare and aging sector of Western North Carolina.

Modifying the Engineering Technology Curriculum to Incorporate Innovation

The engineering technology (ET) degree at WCU is built on a strong liberal arts foundation of 42 hours. The ET program favors the manufacturing and mechanical engineering disciplines at its core and incorporates hands-on projects into each course. The theme of product development is threaded through the courses and includes extensive solid modeling, design, prototyping, reverse engineering and automation. The large liberal arts sequence results in a squeeze on credit hours and limits adding additional courses to the program. As a result, the initial efforts to inject innovation and creativity into the curriculum meant restructuring existing courses. Two courses, ET461 Project Management for Engineers (3 credit hours) and ET478 Senior Capstone Project (3 credit hours), were linked into a two-semester sequence. The added benefit of this approach meant the senior capstone project could be expanded into a full two-semester activity. The goal of the two course sequence was to create an opportunity for innovation to be expressed in the creation of a new product and gain the confidence in solving open-ended problems. The word "new" discriminates this course from a course where projects are primarily incremental

improvement in nature. The projects in this course sequence must be new and draw the student out of their comfort zone and into the creative process. Further reinforcing this adventure into new operating spaces, senior capstone projects up to this time have focused on innovative new products that would improve the delivery of healthcare.

The focus on of healthcare builds on the foundations of active engagement of the university with the region and collaboration across a broad sector of our community. Healthcare and aging are critical issues for the region. The successes of the university's Center for Rapid Product Realization and the North Carolina Center for Health and Aging (now under construction) have galvanized the attention of the university, government, and business communities on the potential that adaptive technologies can address the serious challenges of healthcare and aging. However, most of the Engineering Technology students know very little about healthcare and the problems healthcare providers are encountering. The experience reinforces the vision of their engineering profession as problem solvers to the broad community. The project selection and pre-development process has been initiated in the six months before the first course begins with brainstorming sessions with personnel from regional hospitals, nursing facilities and with the faculty in the College of Health Sciences. This gathering of problems and potential new products is supported by the *Innovation Collaborative for Adaptive Technology in Healthcare and Aging,* a collaboration of fourteen healthcare institutions in western North Carolina committed to improving healthcare in the region.[4]

Course Plan

The first course in the sequence seeks to give the students the tools of project management (PM), present those tools within the context of the process of new product development (PD) and apply both PM and PD to their senior capstone project, which develops a new product. The goals of the course are to provide: 1) a learning opportunity that requires out of the box thinking and resolving an open ended problem, 2) an in-depth exposure to the use of project management tools and software; 3) a real experience using these tools to plan and control a project; and 4) the planning and structure for the senior integrated design project. The class uses Microsoft Project© as the software tool for scheduling and project planning. Each of the basic PM tools is applied to the student's senior project.

Two textbooks are used in the course: Project Management: A Managerial Approach, by Jack R. Meredith & Samuel J. Mantel, Jr. [5] and Winning at New Products by Robert G. Cooper[6]. The course uses a selection of readings from each of these texts moving back and forth between books during the semester. The student's capstone project is taking shape as the course content is introduced as shown in Figure 3. The result is a cohesive course applying project management to the Stage/Gate process of product development. Project management skills that are learned include creating work breakdown structures (WBS), Gantt charts relating the tasks, schedules with the critical path identified, and formal trade studies.

The core theme of Dr. Cooper's book is the Stage/Gate process in which product development moves through stages in which multi-disciplinary approaches are applied. This course applies the Stage/Gate approach to the students' capstone project. The first and second semester are linked through this series of stages and gates. The gates, which are defined by the instructor,

ET 461 Project Management for Engineers						
	Project Management		**Product Development**		**Capstone Project**	
Week	**Topic**	**Reading Assignment**	**Topic**	**Reading Assignment**	**Project Milestones and Presentations**	**Homework Assignments**
1	Class Introduction Overview of Project Management (pg 1-24)	Lessons for an Accidental Profession pg 27-37				Start thinking about Creative Juice Competition and Make teams (3)
	Teaming Exercise					
2	Project Selection from Companies Point of View	Chapter 2 pg 40-53		Chapter 4 pg 83-112		Register for Creative Juice
			Critical Success Factors	Chapter 5 pg 129-153		
3			Stage Gate Process	Chapter 5 pg 113-129	Project Ideas	
		Chapter 5 pg 239-259	Review SG process and Goals		Discussion of Project Ideas	
4	Scope of Work and Work Breakdown Structure		Review Project ideas			Expand WBS for event of your choice, bring on memory stick
	WBS and demo MSProject	Go through tutorial on MSProject http://www.profsr.com/msproject/msproj00.htm			Develop structure and plan for Creative Juice	Go over Event WBS
5	Discussion of WBS for projects, work on WBS examples				Select project and Team Formation	Precedecessors Relationships for event
	Project Scheduling	Chapter 8 pg 379-390		Submit JUICE on 9/21	Review project WBS	SUBMIT JUICE PRODUCT by 9/20
6	Project Scheduling and student examples	Chapter 8 pg 390-399	SDI Presentation		Hand in WBS for project to 3rd level Do SDI survey	Schedule for Event
					Hand in Executive Summary of Project	
7	Schedule examples					
	Review for exam				Proposal	
8	**Mid Term Exam**					Project Books Due
	FALL HOLIDAY- NO CLASS					
9	FALL HOLIDAY- NO CLASS					
	Review tests, log books	shortened for BofG		Chapter 7 pg 178-194		
10				Chapter 7 pg 194-212	**Project Presentations**	
		WBS on the board and team work				
11			Discussion Discovery to Development			
	Patent and Budgeting Lecture					Patent Search- Team Report
12	READING DAY No classes					
	IRB and Collecting Data	Chapter 7 pg 333-346				
13	Budgeting	Chapter 7 pg 372-378				Budget exercise
	Budgeting Exercises and Project Budgets	Best Practices Guide				Net Present Value homework
14	Trade Studies/Trade off Analysis		Trade off Study			**Course Evaluation Begins Trade off Study**
Lab	Presentations Trade Study			Chapter 9 pg 252-277	Bill of Materials	
15			Testing and Validation		**Project Budget**	Project Books Due
	Thanksgiving	No class				
16	Review				Sources Identified and Orders Placed	
	FINAL EXAM					
	Presentation with Review Panel	12:00-2:30pm			**Gate 2: Conceptual Design**	

Figure 3. The first semester of the sequence has three components integrated together: the tools of project management, the Stage/Gate process of product development and the initiation of the senior capstone project.

specify each set of deliverables and the criteria for measuring success. The five gates used for the two courses are shown in Figure 4. Notice at Gate 2 the teams are required to have developed at least three viable design concepts. This requirement was added to Gate 2 after it was observed that the students tended to become prematurely attached to the very first option that looked reasonable. Frequently this option subsequently failed and the team had difficulty recovering within the timeframe of the course.

Capstone Project Gates	
Gate 1 Proposal Initial Market Assessment, Product Requirements Conceptual Approach Team Charter and Capabilities WBS and Schedule Presentation	**Gate 3** Preliminary Design Review (PDR) Design Complete, BOM and Procurement completed, Hazard Analysis Completed IRB application submitted Presentation
Gate 2 Conceptual Design Review (CDR) Refinement of Product Requirements Three Conceptual Designs Revised WBS and Schedule Update Cost Estimate Preliminary BOM with Long lead items identified External Review Presentation	**Gate 4** Critical Design Review (CDR2) Prototype Completed, Test Plan finalized **Gate 5** Testing Completed Modification completed Final Project Presentations to External Reviewers

Figure 4. Student Capstone courses are structured around the Stage/Gate process and the projects must meet the requirements of five gates.

The capstone project in the ET program is a team activity with the team size varying from 3-4 students. The authors have found that more than four on the team is difficult to manage and keep all members contributing to the effort. Several techniques have been used for the creation of the teams including self-selection, assignment by common project interest and assignment by mixing high and low GPA. Problems and successes have been observed in all the approaches and at this time no technique has been demonstrated to be superior. The most unpopular approach with the students, but the one that has the highest fidelity with the real world, has been the assignment of teams by the instructor. The "best" result has been a balance of self-selection through common interest in a specific project. Students select and prioritize the project topics they prefer and the instructor then matches and forms teams based on that selection.

In the coming classes, the authors are planning to use the "Teammaker" interview survey provided in the Comprehensive Assessment of Team Member Effectiveness tool (CATME) to assist in forming teams based on project preference[7,8]. This survey gathers information on the individuals themselves and the constraints on team participation. The CATME survey information, which can be customized for the particular class, includes gender, race, GPA, class year, major, off campus/on campus housing, skills, preferred team role, schedule, commuting or not, and employment. It is up to the instructor to create selection algorithm utilizing these factors.

In the most recent classes, students were asked to fill out the Strength Deployment Inventory (SDI)[9]. The SDI explores how the behavior of individual people changes in response to conflict. The SDI can be a valuable tool in creating an environment that deals with the normal conflict experienced in team activities. In this case, the authors only used the SDI to open up the discussion of conflict management and did not use it later in the course.

At the beginning of the semester, the class is presented with a list of projects gathered from the brainstorming sessions with healthcare providers and solicitations from regional firms. Each project has a faculty member advisor as well as a technical mentor conversant in the application. Technical mentors have been critical to the success of the projects which have ranged from orthopedic surgeons to nurses to physical therapists. The nurses and physical therapists have come from both active practitioners and university faculty. Once the teams have been formed based on project preference, the first task for the newly formed teams is to develop a team charter.

The grading system for the first semester has five components: traditional assessment through exams and homework (35%), participation in reading discussion and homework evaluation (20%), team presentations as evaluated by external reviewers (30%) and finally 15% from peer to peer evaluation. The two exams in the semester are taken primarily from the readings and discussion. Several individual homework activities were assigned and graded. For example, students were asked to create a work breakdown structure, task relationship and schedule for a family celebration or party. A second example was to perform a formal trade study on the purchase of a vehicle.

At each gate, student teams made presentations and handed in document packages for review. External reviewers are made up of the team mentors augmented by marketing and business development professionals from the area. Peer to peer evaluation is made at each gate as part of the process using the online CATME peer evaluation tool [8]. The student has access to his/her evaluation immediately after the survey is completed and is able to make adjustments as indicated by the survey. In addition the CATME tool provides the faculty member insight into problems that are occurring within the teams which allow the faculty member to take corrective action.

Early in the semester, the class is asked to form teams and participate in the Creative Juice Competition[10]. The 2008 Competition focused on the creation of new products from a throw away item. The goal of this activity was to encourage out of the box thinking and strengthen the concept of the engineer as an environmentally responsible member of society. Teams had ten days to complete the project and upload a video entry to YouTube for judging. The compressed ten day timeframe was an excellent learning opportunity for real practical project and time management.

The second semester is focused on the capstone project. The grading system builds on the stage/gate structure developed in the first semester. The three gates are each worth 25% of their grade. The 25% is divided according to the gate deliverables. For example, at Gate 3, 10% of the final grade is awarded to completeness of the design, 5% to the quality of the Failure Modes and Effects Analysis, 5% to having the materials needed for the project delivered, and the final 5% awarded on the presentation of the report itself. The remaining 25% of the grade is awarded on the basis of the quality of their design notebooks and the student's participation in the class discussion.

Project Examples

In three years, eighteen projects have been completed. The maturity that these projects attained varies considerably. Some of the most successful are described on the following page.

Figure 5. Student and orthopedic surgeon create rehabilitation device for patients recovering from total knee replacement.

Total Knee Replacement Rehabilitation Device
The project sought to develop a device for home use to assist the patient in achieving full range of motion following a total knee replacement operation (see Figure 5). Immediately following the surgery, scar tissue forms around the new knee components. To prevent this scarring from freezing the knee and limiting the range of motion and flexibility, it is necessary to stretch the knee several times a day. No device exists to assist the patient in this exercise and several student teams working with an orthopedic surgeon developed a low cost device to assist the patient. Patent disclosures have been submitted including the students as inventors.

Wheel Chair Leg Support Storage
Patients using wheel chairs in nursing homes and hospitals often remove the leg supports so that they can propel themselves without assistance. The leg supports become separated from the chairs and are left all over the facility. The problem occurs when a subsequent patient requires the leg support and of course none are to be found causing the facility to buy replacements. The student team working in the hospital maintenance personnel developed a tethering and storage appliance for the wheel chair that allows removal of the leg support but prohibits separation of the support from the chair.

Wrist Rehabilitation Device
Wrists are joints that are often broken and injured. A student team working with an occupational therapist developed a rehabilitation device for the wrist that can double as an exercise machine and as an assessment tools. The device is able to operate in the three different motions of the wrist and measure the strength and range of motion of this joint.

Head Restraint for Radiation Therapy
Radiation therapy is a common treatment for brain tumors. It is important for the radiation to be concentrated on the tumors while limiting radiation damage to healthy surrounding tissue. Motion of the patient's head is limited by a plastic constraint but possible movement of the patient's head is still beyond the desirable limits. A student team working with radiation physicists and oncologists applied basic principles of mechanics to dramatically reduce the undesirable uncertainties.

Student Feedback

The sequence of courses has evolved over the past three years. The Student Assessment of Learning Gains tool (SALG) was used to explore student response to the approach[11]. Not surprisingly, students have expressed a high-degree of value for the course and relevant to the success in their first jobs. Their response is not surprising and is an expected outcome of the integration of their studies in the capstone project. The SALG survey provides evidence that the student feel they have attained a useful proficiency in the fundamental PM tools as well. Following the evaluation of the SALG survey, students in the second semester were invited to discuss the results and further elucidate on the conclusions. One result of these small group discussions was that the Creative Juice competition was identified as highly valuable and worthy of repeating. This opinion ran counter to the authors' evaluation that it required too much time for the value gained. The students suggested that the goal of the competition be emphasized further at the beginning of the course.

Summary

The integration of project management, product development and the senior capstone course has proved to be a successful course structure. The favorable student response to the two course sequence has led to the adoption of this approach by the two other programs, Electrical and Computer Engineering Technology and Electrical Engineering, in the Engineering and Technology Department. This commingling of disciplines, electrical, mechanical and computer engineering, sets the stage for interdisciplinary capstone projects. In coming years, it is expected that multidisciplinary teams will be formed to tackle a broader range of more complex and challenging projects.

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